

## IMPROVING THE FUNCTIONING RELIABILITY OF THE INFORMATION MANAGEMENT SYSTEM ELEMENTS, USING BUILT-IN DIAGNOSTIC TOOLS

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### ABSTRACT

**Context.** In the modern world, information management systems have become widespread. This makes it possible to automate the technological processes of enterprises of various sizes. Many information management systems include wireless and autonomous elements. Autonomy, in this case, means the ability of the system elements to function for a certain time without additional energy supply. In this regard, such a parameter of operational reliability as the battery life of a system element becomes one of the most important. One of the main tools for improving the reliability and fault tolerance of information management system elements – is the use of a modern diagnostic system.

**Objective.** The aim of the work is to develop a method for increasing the reliability of the functioning of autonomous elements of information management systems. It includes the creation of a model of an information management system and an algorithm for reasonable redistribution of diagnostic functions, as well as a software implementation of the developed algorithm, which confirms its higher reliability indicators in comparison with other algorithms.

**Methods.** The basic model was the Preparata-Metz-Chen model. On its basis, a new model of the system was built, including the structural and logical description of the elements and the determination of the way of their interaction. The elements were classified by the degree of criticality of the functions performed in the system. On the basis of the developed model and description of the elements, an algorithm was developed for the reasonable redistribution of the diagnostic load, which made it possible to reduce the average energy consumption of the elements and thereby improve the reliability indicators. A software implementation of the developed algorithm was created, which allows to numerically evaluate its advantages. The developed and existing algorithms were compared.

**Results.** A model of information management system has been developed. In such a system, it is proposed to use an integrated test diagnostics system. This diagnostic system implements algorithms for redistributing the diagnostic load. To determine the importance of the characteristics taken into account, a linear criterion was chosen, as the most studied and fastest in application. A software model, that implements the developed algorithm and makes it possible to compare it with existing algorithms, has been developed. A study of the software model with various parameters was carried out and, based on the results of the software simulation, conclusions were drawn about the possibilities of improving the algorithm and directions for further scientific research were formulated.

**Conclusions.** The usage of the developed algorithm makes it possible to increase such a characteristic of the reliability of the elements of the information and control system as the mean time of failure-free operation (mean time between failures) by increasing the operating time of autonomous elements without recharging. When carrying out software modeling of the developed and existing algorithms, the advantages of the first were confirmed, and theoretical possibilities for its improvement were formulated.

**KEYWORDS:** autonomy, reliability, elements of an information management system, diagnostics, performance characteristics, dynamic distribution algorithm, software model, built-in test diagnostics.

### ABBREVIATIONS

IMS is a Information Management System;  
BC is a Battery Charge;  
FDD is a Fault Detection and Diagnostics;  
UC is a Universal Controller;  
CNN is a Convolutional Neural Network;  
MLP is a Multilayer Perceptron;  
TDT is a Test Diagnostic Tools;  
OD is a Object of diagnostic;  
DA is a Diagnostic agent;  
TD is a Test Diagnostics;  
FC is a Functional Control.

### NOMENCLATURE

$N_{cr}$  is a number of critical elements of the system;  
 $N_{mCr}$  is a number of middle-critical elements of the system;

$N_{nCr}$  is a number of non-critical elements of the system  
 $P_{tr}$  is a threshold power level;  
 $\Delta P_t$  is a power cost of one diagnostic test;  
 $\Delta t$  is a diagnostic interval;  
 $t$  is a working time;  
 $i$  is a serial number of the element;  
 $P_i(t)$  is a charge power of the  $i$ -element at time  $t$ , normalized to the range [0; 1];  
 $CPU_i(t)$  is a CPU load of the  $i$ -element at time  $t$ , normalized to the range [0; 1];  
 $IMP^{CHAR}$  is a numeric importance of the element characteristic;  
 $N_i^{checks}(t)$  is a distributed number of checks for  $i$ -element;  
 $N_{OE}(t)$  is a number of operable elements at time  $t$ ;  
 $N_{OE}^i(t)$  is a function to determine is  $i$ -element is operable;

$OE$  is an integral characteristic of operable elements number;

$N_{checks}$  is a number of checks;

$K_i^{POW}$  is a power coefficient of the  $i$ -element;

$K_i^{CPU}$  is a CPU coefficient of the  $i$ -element;

$N_{checks}(t)$  is a number of possible checks at moment  $t$ ;

$N^{CHAR}$  is a number of characteristics in a complex coefficient;

$N_{el}$  is a number of elements in system of each type;

$T$  is a time of the diagnostic finish.

## INTRODUCTION

Nowadays, IMS are widely used. They allow corporations to automate their technological and business processes [1]. Current trends of their effective usage involve the use of wireless information transfer technologies to ensure the autonomy of the system and its elements. Autonomy is to increase the up-time of the IMS elements without additional supply of energy.

Wireless technologies and autonomy of the elements create additional factors of the system usage. These factors should be taken into account for planning routine maintenance. Because cost of the routine maintenance is directly proportional to the number of failures of the system elements.

For example, some fuel company has fully automated oil rig with autonomous fire-detection sensors. So, oil rig is commonly far away from command centre. If battery of the element (sensor) running out 2 times a week (or other failures), instead of one time – cost of the maintenance becomes 2 times more then it could be. Common cost includes the transfer cost, additional worker salary, etc.

So, improving reliability of the autonomous IMS elements should be considered for everyone who wants to have highly effective system and spend money efficiently.

**The object** of study was autonomous elements of information management system with wireless communication channels.

**The subject** of the study is development of a method for increasing the reliability of the functioning of autonomous elements of information control systems, including the creation of a model of an information control system and an algorithm for justified redistribution of diagnostic functions, as well as a software implementation of the developed algorithm.

**The purpose** of the work is increasing reliability of the autonomous elements of the wireless information-management systems by increasing the operating time without recharging, by increasing the operating time of autonomous elements without recharging.

## 1 PROBLEM STATEMENT

It was found, that in an IMS system with built-in diagnostic tools, the existing diagnostic load balancing algorithms are unreasonable in relation to the current state of the system elements and thus negatively affect their reliability.

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To solve the problem of unreasonable distribution of the diagnostic load, it was decided to develop a method for increasing the reliability of IMS elements and a software package that allows one to obtain a comparative characteristic of the developed and existing algorithms.

Therefore, the main goal of the algorithm is to define the function (1) to recalculate (redistribute) the number of checks for each element before every diagnostic cycle. Input parameters: the classification of the elements of the system and their quantity ( $N_{Cr}$ ,  $N_{mCr}$ ,  $N_{nCr}$ ), the threshold power level of the element ( $P_{tr}$ ), cost for diagnostic test ( $\Delta P_i$ ), the diagnostic interval ( $\Delta t$ ). Current values of characteristics of the elements (in current work we use  $P_i(t)$  and  $CPU_i(t)$ , but number of characteristics is expandable) and their weight coefficients ( $IMP^{CHAR}$ ) are also should be used:

$$\begin{aligned} N_i^{checks}(t) &= f(N_{nCr}, N_{mCr}, N_{Cr}, P_i(t-\Delta t)), \\ CPU_i(t-\Delta t), IMP^{CHAR}, i &\in [1, N_{nCr} + N_{mCr}]. \end{aligned} \quad (1)$$

A characteristic that will be an indicator of the effectiveness of the developed algorithm is an integral indicator of the number of operable elements of the system. To calculate it, we should declare power level of each element at time  $t$  and number of operable elements of the system at time  $t$ :

$$\begin{aligned} N_{OE}(t) &= f(N_{OE}^i(t)), \\ N_{OE}^i(t) &= f(P_i(t), P_{tr}), \\ P_i(t) &= f(P_i(t-\Delta t), N_i^{checks}(t), \Delta P_i), \\ i &\in [1, N_{nCr} + N_{mCr}]. \end{aligned} \quad (2)$$

Then the goal of the developed method will be to increase the numerical value of the resulting function over a finite time interval, the beginning of which coincides with the beginning of the functioning of the built-in diagnostic system:

$$OE = f(N_{OE}(t)). \quad (3)$$

In addition, the criterion for the effectiveness of the developed algorithm will be a decrease in the average rate of change in the values of the resulting function (a smooth change in the number of workable elements). This allows reducing the cost of the batteries replacement.

It is also an important task to determine the conditions and boundary values of the parameters of the function, at which the developed technique is superior to the existing algorithms.

## 2 REVIEW OF THE LITERATURE

In this paper, reliability of the IMS elements is understood as up-time of the element, when the BC is higher than the minimum level. Minimum level of the elements BC should be defined as system requirement.

So, the IMS system reliability – is number of elements, whose BC is higher than minimum level.

The load of control processors significantly affects the discharge speed. In this regard, ensuring the reliability of the functioning of the IMS elements [2] by increasing up-time of the element is arises as a question.

One of the main tools to improve the reliability and fault tolerance of IMS elements – is usage of a progressive diagnostic system that meets modern requirements [3]. Diagnostic systems are divided by type into external and built-in. Each type is used in accordance with the reliability requirements of the system. The built-in test diagnostic system is characterized by the usage of diagnostic tools, built into the IMS elements. The advantages of the integrated [4] diagnostic systems includes, for example, the following:

1. The absence of the usage of the expensive and complicated in the deployment and administration diagnostic system.

2. More complete and adequate diagnostic information, characterizing a specific element of the IMS.

In this paper, the combined test diagnosis system will be investigated. UC is responsible for the distribution of diagnostic functions and functional control. Special tools, built into IMS elements structure, perform test diagnostics.

The use of built-in diagnostic tools [5] takes part of the productivity of control modules (processors, controllers) of IMS elements. The performance resources of the elements (testers), assigned to perform the diagnostic functions, are spent on the formation of the test, transmission and reception of data and their subsequent processing. In order to avoid the rapid discharge of batteries and malfunctioning, the article proposes a methodology for redistributing diagnostic functions between system elements. It allows reducing the load on the most important elements of the system or elements with a low battery charge. This will allow them to reduce the rate of discharge of the battery [6] and increase battery life without recharging. As a result, the reliability of the functioning of the IMS elements increases [7].

So, the problem noted above is quite relevant. At various times, the staff of IPU RAN named after V. A. Trapeznikova: Vedeshenkov V. A. [8], Aminev D. A. [9] and some others were interested in this problem. Also, our foreign colleagues, such as Woohyun Kim, James E. Braun (Herrick Laboratory, Purdue University, Mechanical Engineering, West Lafayette, IN, United States)[10], Xudong Li (National Space Science Center, Beijing, China) [11], Barry Dowdeswell, RoopakSinha, Stephen G. MacDonell (Auckland University of Technology, Auckland, New Zealand) [12] also dealt with similar issues.

In particular, in [8] a method was proposed (Barsi-Grandoni-Maestrini model) for self-diagnosis of modules and communication lines of digital systems with

reconfiguration. This allows stable multiple failures of a limited number of components. The method [8] is based on the principle of expanding domains.

In [9], existing methods of self-diagnosis were considered. Possibility of their application in the diagnosing a distributed radio-technical surveillance system framework was described. An approach to reconfiguring the system depending on the diagnostic results is proposed.

[10] discusses an approach to the design of FDD systems that have the potential to improve energy efficiency while reducing maintenance costs. To achieve this goal, virtual sensors and failure impact models are implemented that require only inexpensive measurements to detect the cause of failure, severely diagnose the failure, and evaluate performance degradation.

In [11], an adaptive built-in diagnostic system is considered. It actively uses transfer learning by developing an integrated approach for troubleshooting with different types of components. Two deep learning techniques are used: CNN and MLP, to train multiple basic models with a set of input data.

In [12], methods for detecting and diagnosing malfunctions used in the field of control in the aerospace, automotive and industrial fields are described. Each of these sectors uses specific techniques to meet different diagnostic needs. One of the most important gaps is the problem of resource efficiency in wireless information management systems.

Thus, it is worth noting that most of the papers on this topic consider diagnostic errors and problems in the data transmission channel as a reason for reconfiguring the diagnostic system. This is undoubtedly very important, but it is also important to take into account the current workload and performance of the system and its elements, because the diagnostic processes additionally load the resources of the system elements, leading to an increase in the likelihood of their wear and tear, failure and lower productivity.

### 3 MATERIALS AND METHODS

Figure 1 shows a block diagram of the developed TDT [13].

This system contains functional elements (devices that directly perform the functions of the system), the reliability of which must be increased. A control and configuration device – UC is necessary for the distribution of functional tasks, collection results of execution and configuration of system elements. The functional elements communicate with each other and the UC via wireless information transmission channels [14]. Next, we will describe the built-in test diagnostics system.

In this system, it is assumed that each functional element of the IMS system, depending on the configuration, can be a test object or a tester. The configuration of each element is set by the UC, which

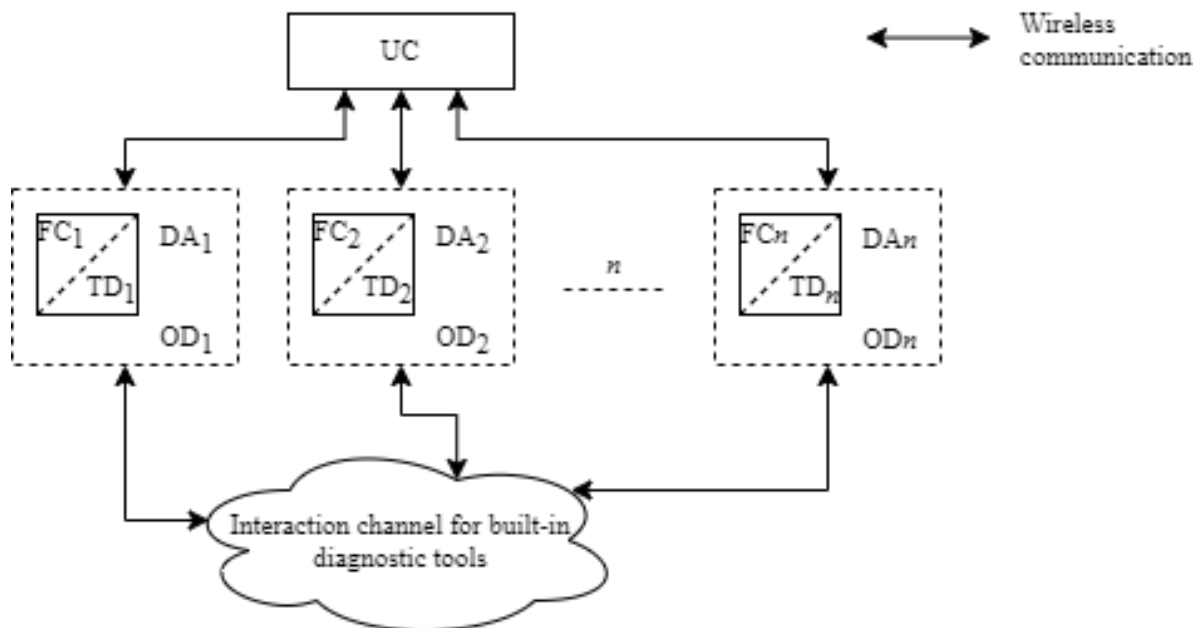


Figure 1 – Element structure of the developed test diagnostics system

also performs functional control (monitoring). The OD implements DA – a software and hardware module that performs the following functions:

1. Tester – formation of tests, transmission, reception and processing of diagnostic information.
2. TD – acceptance of the test and the formation of the response.
3. FC – receiving requests and generating a response about its technical condition (monitoring).

Thus, having entrusted the tasks of dynamic reconfiguration of the built-in test diagnostics system to the UC (without spending the resources of the functional elements (objects of diagnostics)), we will try to increase the reliability of the IMS elements.

In the developed methodology, the diagnostic model of the Prepare – Metz – Chen [15] was taken as the basis, in which the model is represented in the form of a graph whose vertices are the elements of the system and the edges are the inter-element diagnostic connections.

This means that the edge indicates the direction of the diagnostic tests. Also, in this model, each element is diagnosed once, by one diagnostic element – an agent. The novelty of the developed method consists in taking into account the performance characteristics of the IMS elements when distributing diagnostic functions between these elements. Such a system consists of elements of the same type, capable of diagnosing each other with the same tests in terms of resources and time spent.

You can divide the system into several blocks of the same type. In this case, the presented model will describe each block of the system separately, but collectively present the same diagnostic results as if it were the same for different types of elements.

To improve efficiency, you need to use the elements in different ways. The number of classes can be different (number of characteristics, number of elements). Features of the developed model

1. All elements must be divided into 3 classes:
  - a. Critical – those elements that are entrusted with the most important and costly operations in the system, they must be diagnosed in the first place, and not used as a diagnostic tool.
  - b. Medium criticality – elements that are both diagnosed and are diagnosed. Half of this set of elements diagnoses at a certain point in time, when the remaining is diagnosed.
  - c. Non critical – they are constantly used as diagnostic elements. Least loaded system elements.
2. The UC covers the energy and computational costs of the reconfiguration of diagnostics. That is why, this process does not consume the power of diagnostic and diagnosed elements.
3. Input:  $\Delta t, N_{cr}, N_{mCr}, N_{nCr}, P_{tr}$ .
4. At the first stage of the development of the algorithm, we will take  $\Delta P_t$  as a constant, but in a real situation – the value is a variable that depends on other parameters.

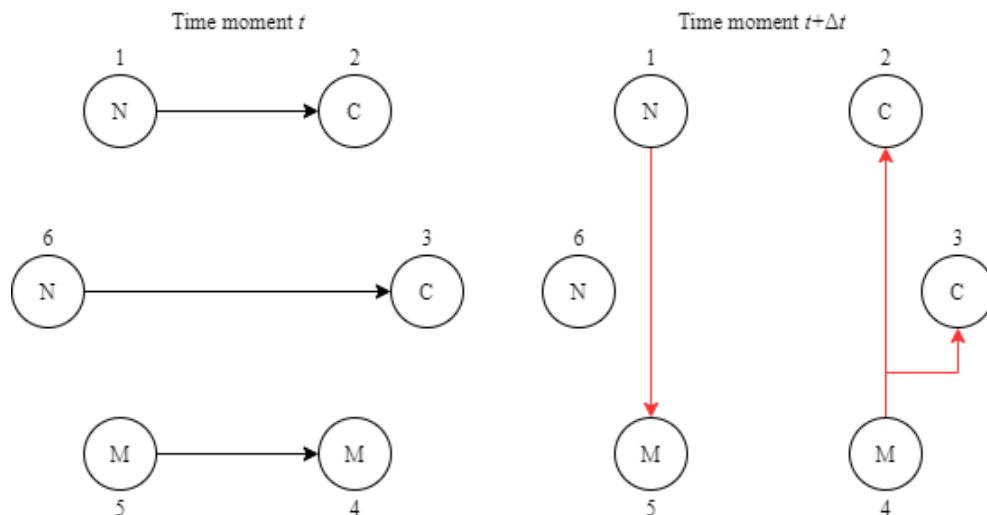


Figure 2 – Example of diagnosis graph for described algorithm at time moments  $t$  и  $t+\Delta t$ . N – non-critical elements, M – medium-critical elements, C – critical elements

On the Fig. 2 we see an example of reconfiguration of the purpose of diagnostic functions of a system consisting of 2 critical elements, 2 elements of medium criticality and 2 non critical elements. At the moment  $t$ , the numerical value of the performance of each element (the calculation is performed by the UC, it collects statistics before each cycle of test diagnostics) made it possible to determine the next diagnostic graph for the system (left graph in Fig. 1). It shows that it is imperative to diagnose critical elements, and at time  $t$  with minimal costs, elements 1, 5, 6 will cope with this. At the next time moment  $t + \Delta t$ , the performance indicators of the elements changed, as well as the numerical estimate, which allowed the UC to redistribute the diagnostic functions.

Let's present an analytical model of the built-in diagnostic system reconfiguration algorithm.

To develop a reconfiguration algorithm, we introduce a model for quantitative assessment of the parameters of the method:

1.  $N_{checks}$ . This value characterizes the number of needed checks in this time interval:

$$N_{checks} = N_{cr} + (N_{mCr} - \left\lfloor \frac{N_{mCr}}{2} \right\rfloor). \quad (4)$$

2. The maximum number of checks for which the resources of each element in the sum are enough:

$$N_{checks}^{max}(t) = \sum_{i=1}^{N_w} N_i(t),$$

$$N_w = N_{nCr} + \left\lfloor \frac{N_{mCr}}{2} \right\rfloor, \quad (5)$$

$$N_i(t) = \left\lfloor \frac{P_i(t) - P_{tr}}{\Delta P_t} \right\rfloor.$$

3. Now we introduce the performance characteristics of each element. We use the dependence from only one characteristic, the expansion will be performed later in this article:

$$K_i^{POW}(t) = P_i(t). \quad (6)$$

4. Number of checks for each element:

$$N_i^{checks}(t) = \frac{K_i^{POW}(t) \times N_{checks}(t)}{\sum_{i=1}^{N_w} K_i^{POW}(t)}, \quad (7)$$

where  $N_{checks}(t)$  will be equal (4) or (5) depending on the conditions described below.

Thus, all the quantities necessary for the development of the reconfiguration algorithm are determined.

Due to the development of wireless technologies [2], autonomous IMS elements have become widespread. Examples of autonomous IMS elements can be (autonomous TP-Link TL-MR3040 routers), energy autonomous products from CISCO (Cisco Aironet 1240), autonomous sensors for monitoring leaks and fire safety in oil fields (Lukoil). It is also relevant for mobile devices and AD-HOC networks [16], since they certainly have an autonomous power supply of the elements [17].

For various information and control systems, the performance characteristics of its elements may be different [18]. Thus, one of the requirements for the developed algorithm is scalability in number of characteristics, which affect the performance of elements.

As you know, a decrease in the battery charge level leads to a malfunction of the elements, which leads to a decrease in such a reliability indicator as mean time between failures. Most modern cells have built-in diagnostics that take up part of the performance of processor devices and, accordingly, accelerate battery discharge. Thus, with redistributing the load of elements with diagnostic functions, it is possible to selectively reduce the discharge rate and increase the reliability indicators of the IMS elements.

A new algorithm for reconfiguring the built-in subsystem of test diagnostics has been developed to perform the main functions of the UC. As a first approximation, we consider one performance characteristic and take  $\Delta P_t = \text{const}$ .

Algorithm diagram is shown on the Fig. 3.

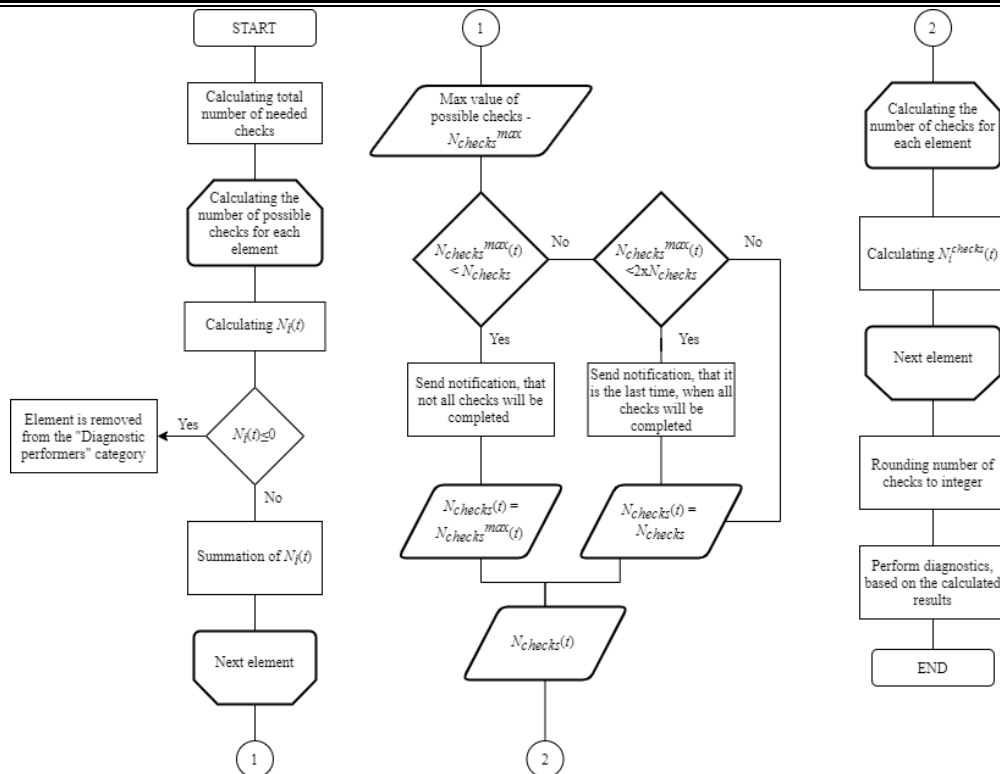


Figure 3 – Scheme of the developed reconfiguration algorithm

1. The first step of the reconfiguration algorithm is to calculate the number of checks that will fall on each diagnostic element at time  $t$  with an interval of  $\Delta t$ . Let us calculate the total number of checks for each moment of time  $t$  according to the (4).

2. The second step is to determine the possible number of checks at a given time, depending on the current battery charge. This number does not depend on the number of characteristics that must be taken into account in the distribution of diagnostic functions. We make the calculation using the (5). If,  $N_i(t) \leq 0$ , then the element is removed from the category of diagnostics with the corresponding notification of AST. Also, if:

$$N_{checks}^{max}(t) < N_{checks}, \text{ then } N_{checks}(t) = N_{checks}^{max}(t).$$

In this case, a notification is sent that not all necessary checks will be performed at the current time. The necessary action in this case is to replace the batteries. And if:

$$N(t)_{checks}^{max} < 2 \times N_{checks},$$

then a notification is sent that the current check is the last full check (that is, all tests will be carried out) and the next one will be incomplete.

So, if two first conditions are false, then:

$$N_{checks}(t) = N_{checks}.$$

3. The next step is to distribute the diagnostic load depending on the performance characteristics of the cells,

and in this case – the current battery charge. For this, we introduce the required coefficient according to the formula (6). Thus, the number of checks per element is calculated by the formula (7).

4. The last step of the algorithm is to round the number of checks to an integer in such a way that the number of checks for an element with a large current charge is rounded up, and for a smaller one, accordingly, down.

5. Carrying out diagnostics according to the performed reconfiguration, sending the results to the UC. Waiting for the end of the diagnostic interval. Go to step 1.

The input data of the algorithm are set at the stage of creating a system based on the class of tasks solved by the system and the necessary requirements for the reliability of the system.

Now, the method of the expansion of the number of considered characteristics will be presented.

In step 3 of the algorithm, the distribution coefficient of checks by the current level of battery charge was presented. To take into account additional parameters, a complex coefficient is required. This coefficient is proposed to be calculated according to the following algorithm.

Let us add one more characteristic of the IMS element – the processor load at the current time. High processor utilization leads to decreased performance, slower performance and faster battery drain. This dependence is because with a high processor load, the diagnostic test execution time will increase, which will undoubtedly lead to an increase in battery consumption. Therefore, a reasonable distribution of diagnostic tasks

between various elements can increase the battery life of an element, as well as improve performance and reliability indicators.

An example of a common specification is processor frequency. As a particular characteristic, one can suggest, for example, the distance of signal transmission between the elements of the system. Here is an example of a modified calculation of clause 3 of the algorithm:

$$K_i^{CPU} = 1 - CPU_i, CPU_i \in [0;1].$$

The difference is necessary to take into account the requirements for improving the characteristics, because the more the processor is loaded, then the worse the conditions for this element to diagnose. For 2 characteristics under consideration, the complex coefficient will look like:

$$K_i = IMP^{CPU} \times K_i^{CPU} + IMP^{POW} \times K_i^{POW},$$

$$\sum_{i=1}^{N^{CHAR}} IMP_i^{CHAR} = 1.$$

To numerically determine the importance of characteristics, several approaches can be used. For example:

1. Mathematical (average, weighted average).
2. The theory of the importance of criteria by Podinovsky [19]
3. Coefficient of concordance (consistency of expert judgment)
4. Fuzzy logic.

For this algorithm, it is advisable to use the average approach to determine the weight coefficients. Its advantages are ease of use, clarity of the distribution of importance characteristics, a large number of algorithms in which it is already used [20]. If necessary, the method can be changed.

Development of a software model in which the developed diagnostic load distribution algorithm is implemented.

In order to check the correctness of the developed algorithm, a software was developed that simulates the operation of the developed algorithm and shows a

**Input**

Number of critical elements

Number of middle-critical elements

Number of non-critical elements

Test power cost

Threshold power level

Diagnosis interval

comparison with other algorithms, when the entire diagnostic load is assigned to one element until its failure. Let us call this algorithm “1 → all”. There are two types: simple and modified. Simple’s gist is, briefly, that one item is assigned as a tester until it fails. Then the next element takes over its responsibilities and works until it fails. Modified algorithm reassign the tester before each diagnostic cycle. Program was written in Javascript (for cross-platform) using the EmberJS framework [21].

Below are the results of the algorithm. When entering input parameters, the program generates the entered number of elements, assigning them random initial values of the battery charge and processor load. From this starting point, the algorithms being compared operate. An example of the generated initial state is shown in Fig. 4.

In the figure, on the left side, we see a panel for entering the system parameters, necessary for the developed algorithm to work. On the right, we see the visualization of the generated elements of the information system according to the entered parameters. Inside each element there are 2 columns – the left one is responsible for the charge level of the element, the right one is for the current CPU load. Before each diagnostic cycle, the CPU value is randomly generated again, the battery power value is reduced depending on the number of diagnostic tests performed. Functions to calculate the needed values (2, 3) to estimate the effectiveness of the developed algorithm are presented in program, so:

$$N_{OE}(t) = \sum_{i=1}^{N_{nc}+N_{mc}} N_{OE}^i(t),$$

$$N_{OE}^i(t) = \begin{cases} 1, & P_i(t) > P_{tr} \\ 0, & P_i(t) \leq P_{tr} \end{cases}, \quad (8)$$

$$P_i(t) = P_i(t - \Delta t) - (N_i^{checks}(t) \times \Delta P_i).$$

The result of the program’s work (Fig. 5) is a graph that demonstrates the calculated by formula (8) number of operable elements. The OE characteristic will be calculated like:

$$OE = \int_0^T N_{OE}(t) dt. \quad (9)$$

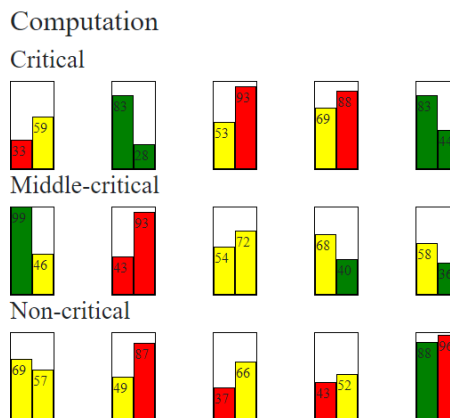


Figure 4 – Example of initial state in developed software



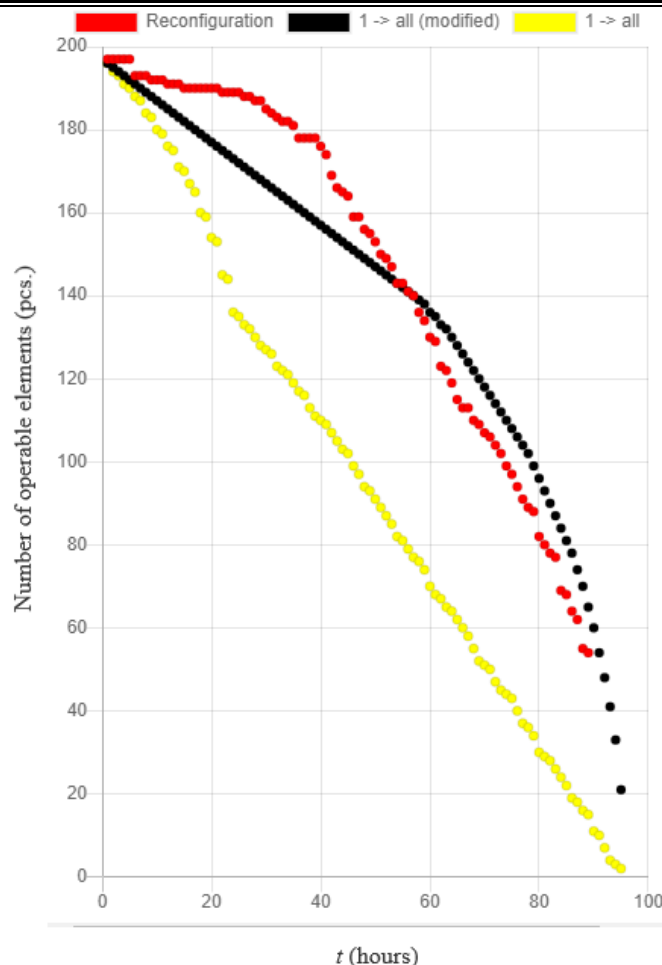


Figure 5 – Example of computation results

#### 4 EXPERIMENTS

We will take 3 system types with different number of elements: 20, 100, 500. It means that the first system will have 20 critical, 20 middle-critical and 20 non-critical elements, second will have 100 critical, 100 middle-critical and 100 non-critical elements, etc. And we will take 2 different  $\Delta P$  values to see, how the complexity of the test (resource needed) affects algorithms efficiency.

Let us analyze graphs. We must visually pay attention to the value of the area under the graph (*OE*) and smoothness in function value decrease. Numerically *OE* can be calculated by (9), but here we can visually analyze this value as area under the graph. On Fig. 6 and Fig. 9 we can see, that in system with low number of elements, developed method works less efficiently then the modified “1 → all” method. However, at the same time we can see that it has the smoothest decline between all methods. It means that elements battery discharge is flowing. This type of discharge is the best way to extend battery and increase the element reliability.

We can see, that increasing the number of elements leads developed algorithm to work more efficient. Number of operable elements on Fig. 7, Fig. 8, Fig. 10, Fig. 11 is more than in other methods. So we can conclude, that if systems have a lot of elements, it’s better to use developed algorithm.

At the same time, we can see the intersection of graphs and method “1 → all” becomes more efficient, when batteries charge is low. We can conclude that in further researches the combined algorithm can be invented. We can take the best from both algorithms and create an algorithm, which will choose the most effective method in current time and situation.

The efficiency become a little bit higher with the  $\Delta P$  cost increasing. We can see, that the difference between operable elements on Fig. 8 is less than in Fig. 11. It means that the algorithm works well in highly loaded systems.



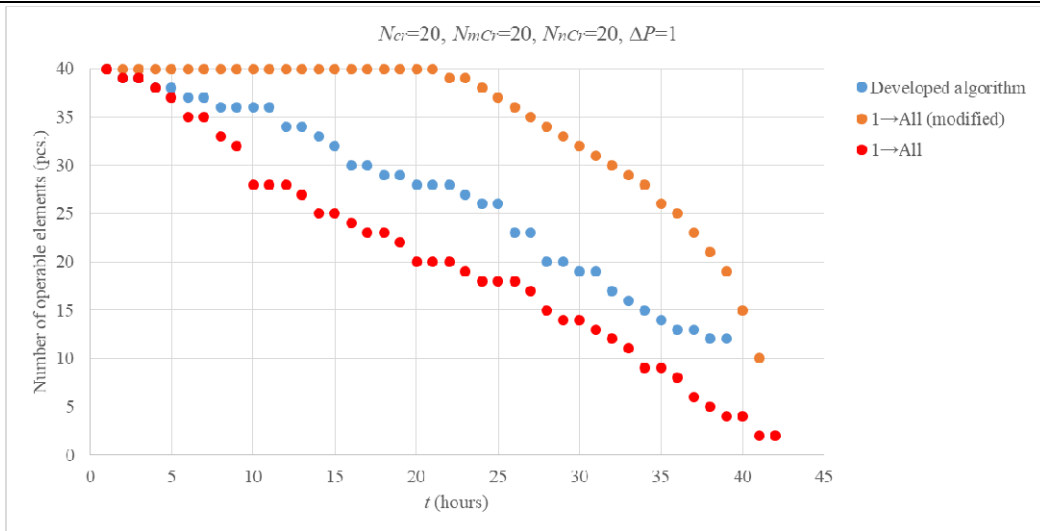


Figure 6 – Experiment graph,  $\Delta P=1\%$  and  $N_{el}=20$  pcs

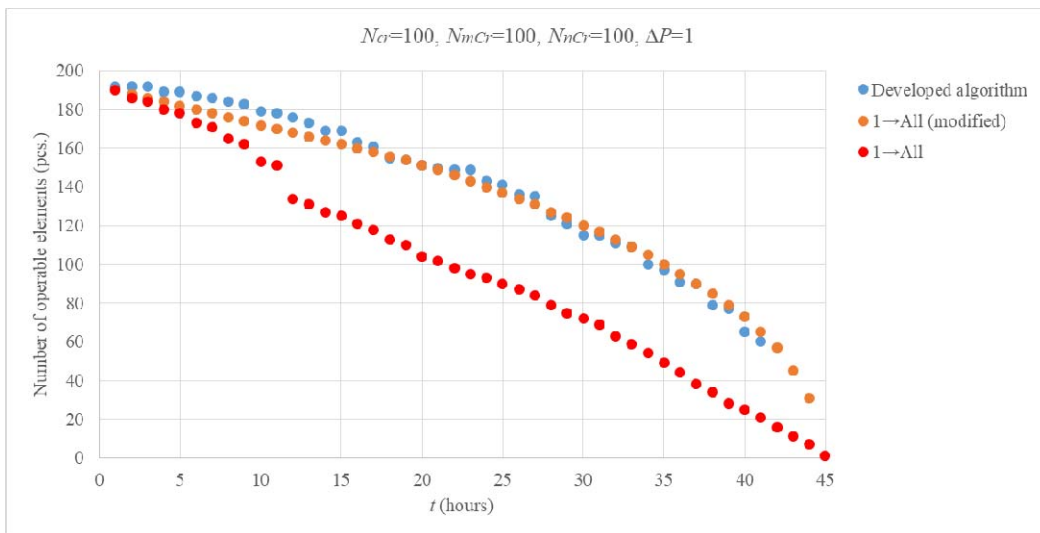


Figure 7 – Experiment graph,  $\Delta P=1\%$  and  $N_{el}=100$  pcs

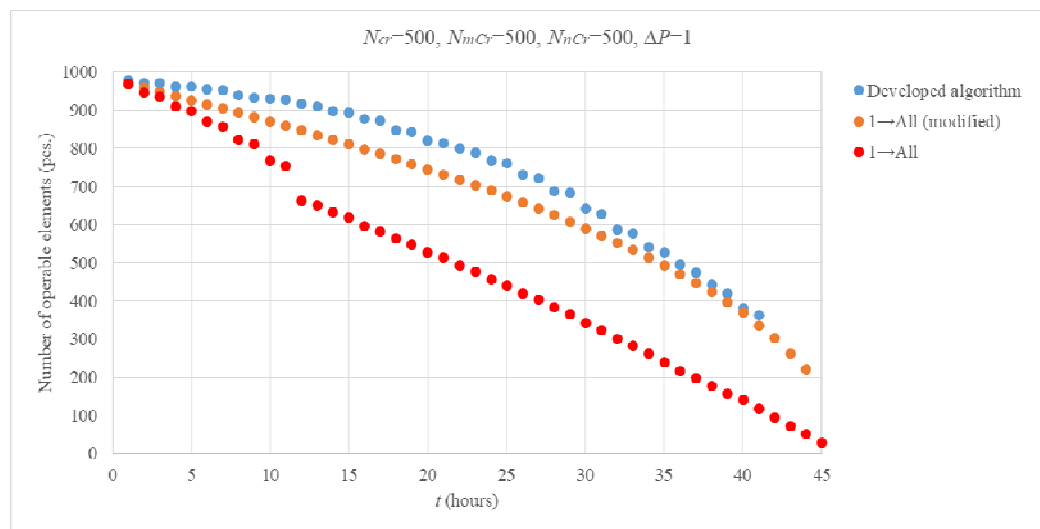


Figure 8 – Experiment graph,  $\Delta P=1\%$  and  $N_{el}=500$  pcs.

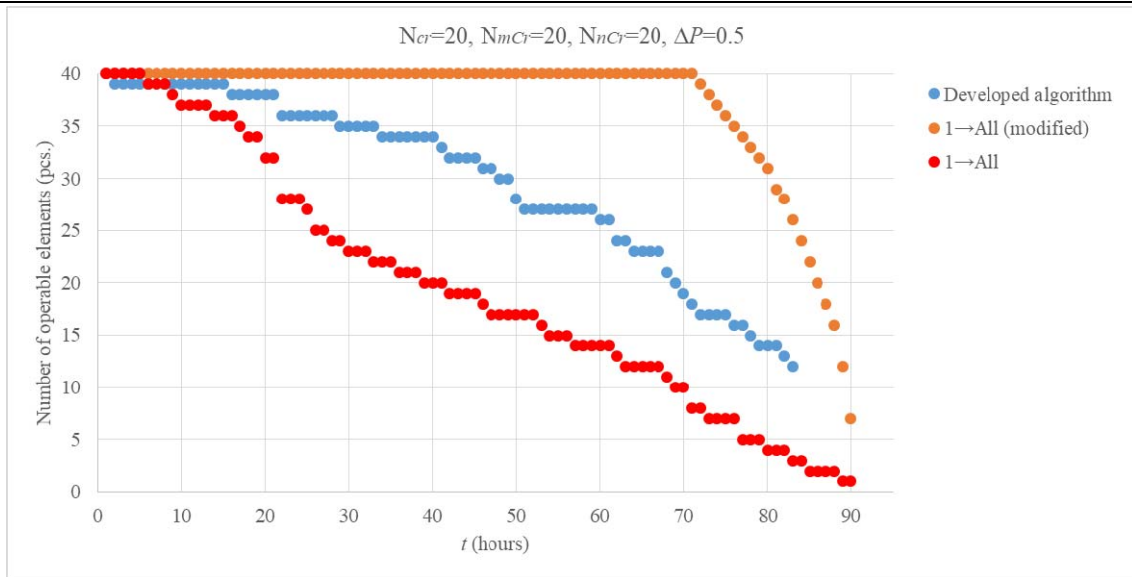


Figure 9 – Experiment graph,  $\Delta P=0.5\%$  and  $N_{el}=20$  pcs.

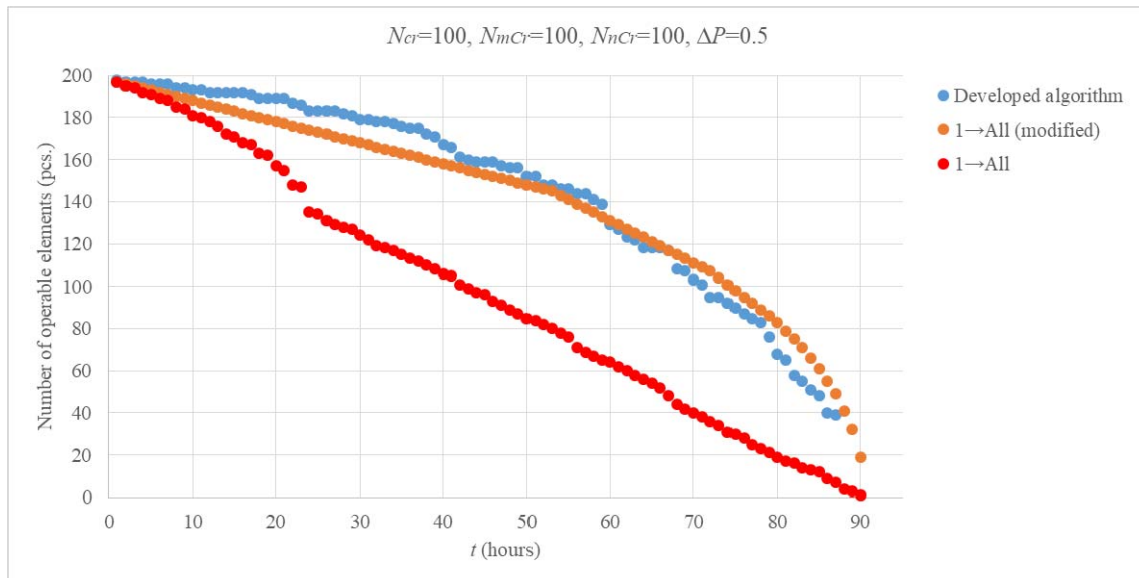


Figure 10 – Experiment graph,  $\Delta P=0.5\%$  and  $N_{el}=100$  pcs.

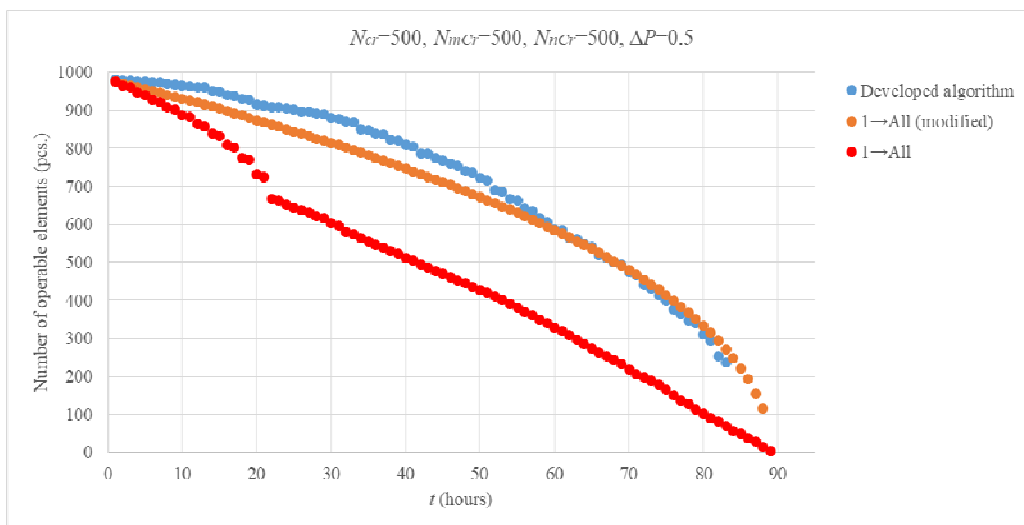


Figure 11 – Experiment graph,  $\Delta P=0.5\%$  and  $N_{el}=500$  pcs

## 5 RESULTS

As a result of the theoretical studies, an IMS model has been developed, to improve the reliability indicators of which it is proposed to use an integrated test diagnostics system. Methods to define the criteria weight were presented. One of them was chosen in the developed model and reasons of it are also presented. A mathematical model has been created for calculating the main indicators of the functioning of the IMS elements. An algorithm for redistribution of the diagnostic load has been developed, which uses the results of calculations according to the proposed model and allows increasing the performance indicators of the system elements.

A software model has been developed that implements the developed algorithm and allows it to be compared with existing algorithms. A study of a software model with various parameters was carried out and, based on the results of software modeling conclusions were drawn about the possibilities of improving the algorithm, and directions for further scientific research were formulated.

## 6 DISCUSSION

The several existing algorithms were chosen for the experiments. Experiments showed some advantages and disadvantages of the developed algorithms as well as advantages and disadvantages of the other algorithms. It helps to understand the best conditions for algorithm usage and improvement possibilities. Combination of best results can help to update the developed algorithm to make it more efficient in other conditions.

Therefore, the best conditions to use the developed algorithm are when the number of elements is higher than 100 (of each type). With an increase in number of elements, we can see an increase in number of operable elements. In system with 100 elements of each type the average increase in the number of work items is 6% compared to modified «1 → all» algorithm and 35% compared to «1 → all». In system with 500 elements – 7% and 45% resp. Also, with the increase in test power cost, the developed algorithm increases the number of operable elements by 2%, meanwhile other algorithms don't show the same result. It shows, that algorithm also works well in systems with high loaded elements.

These results can help to increase the IMS system elements reliability. Smooth and slow discharge of the elements battery and CPU level as a reconfiguration reason can help to extend the life of the battery and functional parts of the elements, which also saves money for routine maintenance.

## CONCLUSIONS

This article presents a developed methodology for increasing the reliability of IMS elements using built-in diagnostic tools. The characteristics of the IMS elements (processor load and battery discharge rate) were analyzed, which significantly affect the reliability of their operation. It is shown that the means of test diagnostics tools (TDT) also affect the indicated parameters, but, to reduce their negative influence, a technique for their reconfiguration is

proposed in the work. It lies on reasonable reconfiguration of the objects of the built-in test diagnostics subsystem based on taking into account the performance factors (processor load) and energy efficiency (battery discharge rate). The developed methodology is scalable in number of characteristics.

**The scientific novelty** of the results is: developed diagnostic model of the built-in diagnostic system and algorithm for its reasonable reconfiguration. Also, to confirm theoretical assumptions, a software simulation program was developed. It makes possible to qualitatively and numerically evaluate the advantages of the developed algorithm.

**The practical significance** of the results of the work lies in the improving the reliability of autonomous elements of the IMS. Increasing the number of operable elements in the current moment of time will help to reduce costs of the element's service and usage.

**Prospects for further research** are expected in the development of algorithmic and software tools for full simulating. It's also expected to improve the method of calculation of the  $\Delta P$  value. It's important, because its value is not constant, it's value should be calculated as two variable function, depends on current processor load and current charge level of the element. Also, it's interesting to combine the best results of several algorithms and update the developed one.

## ACKNOWLEDGEMENTS

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## ПІДВИЩЕННЯ НАДІЙНОСТІ ФУНКЦІОНУВАННЯ ЕЛЕМЕНТІВ ІНФОРМАЦІЙНО-КЕРУЮЧИХ СИСТЕМ З ВИКОРИСТАННЯМ ВБУДОВАНИХ ЗАСОБІВ ДІАГНОСТИКИ

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### АНОТАЦІЯ

**Актуальність.** У сучасному світі широкого поширення набули інформаційно-керуючі системи, які дозволяють автоматизувати технологічні процеси підприємств різних масштабів. Багато інформаційно-керуючих систем (ІКС) мають у своєму складі бездротові і автономні елементи. Під автономністю, у даному випадку, мається на увазі можливість елементів системи функціонувати певний час без додаткового підведення енергії. У зв'язку з цим, такий параметр надійності функціонування, як час автономної роботи елемента системи, стає одним з найважливіших. Одним з основних інструментів підвищення надійності і відмовостійкості елементів ІКС є використання сучасної системи діагностування.

**Мета роботи.** Метою роботи є розробка методу підвищення надійності функціонування автономних елементів інформаційно-керуючих систем, в тому числі створення моделі інформаційно-керуючої системи і алгоритму обґрунтованого

перерозподілу діагностичних функцій, а також програмна реалізація розробленого алгоритму, що підтверджує його більш високі показники достовірності порівняно з іншими алгоритмами.

**Методи.** Базовою моделлю була обрана модель Препарата-Метца-Чена. На її основі була побудована нова модель системи, що включає в себе структурно-логічний опис елементів і визначення способу їх взаємодії. Була проведена класифікація елементів за ступенем критичності виконуваних у системі функцій. На основі розробленої моделі та опису елементів був розроблений алгоритм обґрунтованого перерозподілу діагностичного навантаження, що дозволило знизити середнє енергоспоживання елементів і за рахунок цього поліпшити показники надійності. Була створена програмна реалізація розробленого алгоритму, що дозволяє чисельно оцінити його переваги. Було проведено порівняння розробленого і існуючого алгоритмів.

**Результати.** Розроблено модель ІКС, для підвищення показників надійності якої пропонується використовувати інтегровану систему тестової діагностики. Для визначення важливості врахованих характеристик був обраний лінійний критерій як достатній для вирішення поставлених завдань. Створено математичну модель для розрахунку основних показників функціонування елементів ІКС. Розроблено алгоритм перерозподілу діагностичного навантаження, які використовують результати розрахунків за запропонованою моделлю і дозволяють підвищити показники працездатності елементів системи. Розроблена програмна модель, що реалізує розроблений алгоритм і дозволяє порівнювати його з існуючими алгоритмами. Було проведено дослідження моделі програмного забезпечення з різними параметрами і за результатами моделювання програмного забезпечення були зроблені висновки про можливість покращення алгоритму, сформульовані напрямки подальших наукових досліджень.

**Висновки.** Застосування розробленого алгоритму дозволяє підвищити таку характеристику надійності елементів ІКС, як середній час безвідмовної роботи (середнє напрацювання на відмову) за рахунок збільшення часу роботи автономних елементів без підзарядки. При проведенні програмного моделювання розробленого і існуючого алгоритмів були підтверджені переваги першого, а також сформульовані теоретичні можливості для його поліпшення.

**КЛЮЧОВІ СЛОВА:** автономність, надійність, елементи інформаційно-керуючої системи, діагностика, характеристики продуктивності, алгоритм динамічного розподілу, програмна модель, вбудована система тестового діагностування.

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#### **ПОВЫШЕНИЕ НАДЕЖНОСТИ ФУНКЦИОНИРОВАНИЯ ЭЛЕМЕНТОВ ИНФОРМАЦИОННО-УПРАВЛЯЮЩИХ СИСТЕМ С ИСПОЛЬЗОВАНИЕМ ВСТРОЕННЫХ СРЕДСТВ ДИАГНОСТИКИ**

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#### **АННОТАЦИЯ**

**Актуальность.** В современном мире широкое распространение получили информационно-управляющие системы, которые позволяют автоматизировать технологические процессы предприятий различных масштабов. Многие информационно-управляющие системы имеют в своем составе беспроводные и автономные элементы. Под автономностью, в данном случае, понимается возможность элементов системы функционировать определенное время без дополнительного подвода энергии. В связи с этим, такой параметр надежности функционирования как время автономной работы элемента системы становится одним из важнейших. Одним из основных инструментов повышения надежности и отказоустойчивости элементов ИУС является использование современной системы диагностирования.

**Цель работы.** Целью работы является разработка метода повышения надежности функционирования автономных элементов информационно-управляющих систем, в том числе создание модели информационно-управляющей системы и алгоритма обоснованного перераспределения диагностических функций, а также программная реализация разработанного алгоритма, подтверждающая его более высокие показатели достоверности по сравнению с другими алгоритмами.

**Методы.** Базовой моделью была выбрана модель Препарата-Метца-Чена. На ее основе была построена новая модель системы, включающая в себя структурно-логическое описание элементов и определение способа их взаимодействия. Была проведена классификация элементов по степени критичности выполняемых в системе функций. На основе разработанной модели и описания элементов был разработан алгоритм обоснованного перераспределения диагностической нагрузки, что позволило снизить среднее энергопотребление элементов и за счет этого улучшить показатели надежности. Была создана программная реализация разработанного алгоритма, позволяющая численно оценить его преимущества. Было проведено сравнение разработанного и существующего алгоритмов.

**Результаты.** Разработана модель ИУС, для повышения показателей надежности которой предлагается использовать интегрированную систему тестовой диагностики. Для определения важности учитываемых характеристик был выбран линейный критерий как достаточный для решения поставленных задач. Создана математическая модель для расчета основных показателей функционирования элементов ИУС. Разработан алгоритм перераспределения диагностической нагрузки, которые используют результаты расчетов по предложенной модели и позволяют повысить показатели работоспособности элементов системы. Разработана программная модель, реализующая разработанный алгоритм и позволяющая сравнивать его с существующими алгоритмами. Было проведено исследование модели программного обеспечения с различными параметрами и по результатам моделирования программного обеспечения были сделаны выводы о возможностях улучшения алгоритма, сформулированы направления дальнейших научных исследований.

**Выводы.** Применение разработанного алгоритма позволяет повысить такую характеристику надежности элементов информационно-управляющей системы, как среднее время безотказной работы (средняя наработка на отказ) за счет увеличения времени работы автономных элементов без подзарядки. При проведении программного моделирования

разработанного и существующего алгоритмов были подтверждены преимущества первого, а также сформулированы теоретические возможности для его улучшения.

**КЛЮЧЕВЫЕ СЛОВА:** автономность, надежность, элементы информационно-управляющей системы, диагностика, характеристики производительности, алгоритм динамического распределения, программная модель, встроенная система тестового диагностирования.

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